Color dynamics in hadron diffraction by nuclei

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The interaction eigenstates in quantum chromodynamics are states of the incident hadron with certain values of the color transverse dipole moment. Accordingly, a sum can effectively be taken over all the corrections for inelastic screening of the hadron–nucleus diffraction amplitude.

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1. The corrections for inelastic screening[1] in the Glauber–Sitenko model are known to "brighten" the nucleus, i.e., to reduce the cross section for elastic hadron–nucleus scattering and to increase the cross section for diffractive dissociation.[2] The very first correction,[3] which corresponds to a single event in which new states are formed in the nucleus, leads to a satisfactory description of the data on the total hadron–nucleus cross sections.[4,5] The more complicated corrections cannot be calculated in a model-independent manner. In diffractive dissociation it is not possible to calculate even the first inelastic correction, but estimates show that this correction has an important effect on the amplitude.[2] The eigenstate method makes it possible to effectively sum over all the inelastic corrections to the amplitude for hadron–nucleus diffraction,[2,6,7] but it requires knowledge of the system of interaction eigenstates, which can be calculated only by adopting some specific theoretical model.[6,7]

2. The simplest mechanism for elastic scattering of hadrons in quantum chromodynamics is two-gluon exchange, which leads to a good description of diffractive processes at a nucleon.[8–10] The forward-scattering amplitude of a system of two quarks with a definite relative separation $\vec{\rho}$ in the impact-parameter plane is

$$f(\rho) = i\,\frac{8}{3}\,\alpha_s^2 \int \frac{d^2k}{k^4}\,(1 - e^{-i\mathbf{k}\vec{\rho}})(1 - S_N(k)). \qquad (1)$$

Here α_s is the coupling constant in quantum chromodynamics (its value is discussed in Refs. 8–10), and $S_N(k)$ is the two-quark form factor of the nucleon, given by $S_N(k) = \langle \exp[i\mathbf{k}(\vec{r}_1 - \vec{r}_2)]\rangle_N$, where the average is over the coordinates of the quarks in the nucleon, r_i.

At sufficiently high energies, the motion of the quarks in the incident hadron is relativistically retarded; it thus follows from Eq. (1) that the interaction eigenstates in this model are states with a definite value[1)] of ρ.

3. The partial amplitude for elastic hadron–nucleus scattering in the eigenstate method[6] is

$$-iF(b) = 1 - \langle \exp[if(\rho)\,T(b)]\rangle_h\,. \qquad (2)$$

Here b is the impact parameter of the incident hadron (or meson) h; the average is over ρ, the relative distance between the quarks in this hadron, and $T(b)$ is the profile function of the nucleus. For clarity, Eq. (2) is written in the optical approximation.

Similarly, the partial cross section for diffractive dissociation is

$$\sigma_{diff}(b) = \langle \exp[2if(\rho)T(b)]\rangle_h - \langle \exp[if(\rho)\,T(b)]\rangle_h^2. \qquad (3)$$

Calculations have been carried out with two parametrizations of the form factors: (a) a polar parametrization, $S_a(k)=\mu_a^2/(k^2+\mu_a^2)$, where $a=h, N$; (b) a Gaussian parametrization, $S_a(k)=\exp(-k^2/\lambda_a^2)$. The parameters μ_a and λ_a are expressed in terms of the radii of the hadrons a. If h is a meson, then $f(\rho)$ in the latter case is

$$f(\rho) = \sigma_{tot}^{hN}/2\,[\gamma\ln(1+1/\gamma)+\ln(1+\gamma)]^{-1}[1-\exp(-z^2/4)+C + \ln(z^2/4) - (1+z^2/4)Ei\,(-z^2/4)], \qquad (4)$$

where $z=\lambda_N\rho$, $\gamma=\lambda_h/\lambda_N$, and C is the Euler constant. In the case of a proton the expression for $f(\rho_1,\rho_2,\rho_3)$ is more complicated.

4. Calculations of σ_{tot}^{hA} from Eqs. (2) and (4) show that the total correction for inelastic screening differs only slightly from the first correction[3] for real nuclei.

A "theoretical experiment" has been carried out for the case of diffractive dissociation[7]: The cross section for diffractive dissociation of a pion by nuclei calculated from Eqs. (3) and (4) was compared with the expression in Ref. 11, which does not contain any inelastic corrections (as is the usual case in an analysis of experimental data). The adjustable parameter was σ_{tot}^{xN}, the average cross section for interaction of the system of particles produced with a nucleon; for nuclei in the range ^{12}C–^{208}Pb, the ratio $\sigma_{tot}^{xN}/\sigma_{tot}^{\pi N}$ was varied over the range 0.85–0.65. When $\sigma_{diff}^{\pi A}$ was calculated for the polar parametrization of $S_a(k)$, the parameter σ_{tot}^{xN} generally turned out to be negative. It is thus clear that the conclusion that σ_{tot}^{xN} is anomalously small is a consequence of neglecting inelastic screening (cf. Ref. 2).

5. Previous calculations for diffraction processes have been carried out by the eigenstate method in the quark–parton model.[2,6] The "brightening" of the nucleus in this case occurs primarily because of the passive component of the constituent quarks. In the model under consideration, there is no direct analog of the passive component, since the characteristic time for two-gluon exchange is $t\sim 1/m$. Since the hadrons are colorless, however, the transverse color dipole moment of the hadron interacts with the gluon field of the target, and in the limit $\rho\to 0$ we have $f(\rho)\sim\rho^2$; in other words, the hadron interacts weakly. In contrast with the parton model, for a very thick nucleus $[T(b)\to\infty]$ the transparency of the nucleus falls off, but the decrease is very slow, proportional to $1/T(b)$.

6. Analysis of data on the photoproduction of Φ mesons in nuclei has shown[12] that the cross section $\sigma_{tot}^{\Phi N}$ is much smaller than the values predicted by the additive quark model. Since a Φ meson consists of two heavy s quarks, its radius is much smaller than that of Π and K mesons, with the result that $\sigma_{tot}^{\Phi N}$ is reduced in this model.[8]

7. Equation (2) has been written under the condition that $E/m^2 \gg R_A$, under

which the mixing of hadron components with different values of ρ can be neglected. At intermediate energies the mixing must be taken into account; this step is equivalent to taking into account the limiting momentum transfers and the nuclear form factor.[13] For this purpose, however, we need to know the quark wave function of the hadron.

8. Since the approach of this paper ignores the effect of transverse gluons on the wave function of the relativistic hadron, the model is not capable of correctly reproducing the mass distribution of the cross section for diffractive dissociation. It is clear, for example, that there is no three-pomeron contribution in this case. The model must accordingly be refined.

[1)]This problem is very similar to that of the passage of positronium through matter.

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